

B-Meson Tagging with sPHENIX MAPS Detector

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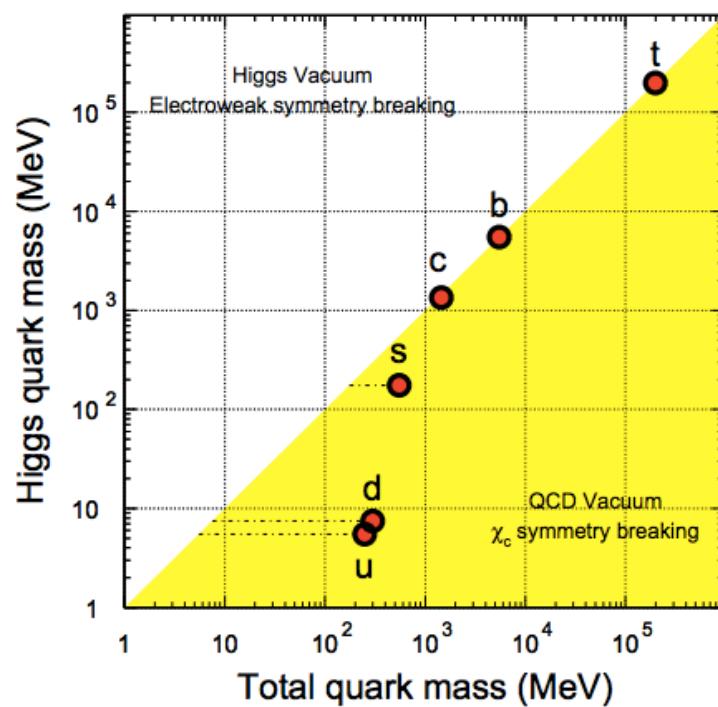
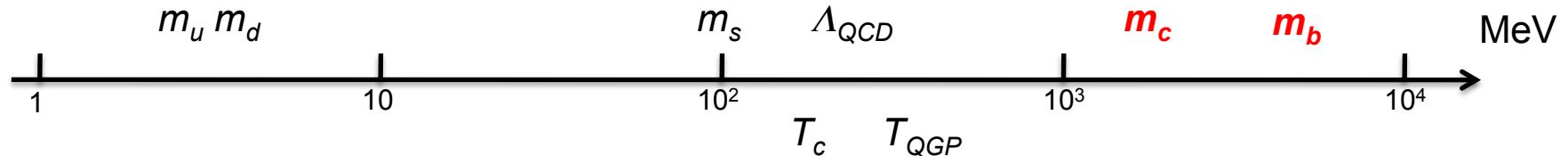


Jan. 25-25, 2017

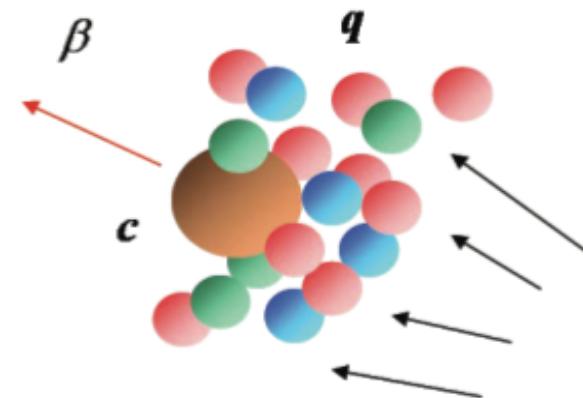
sPHENIX MAPS Pre-proposal Mtg, Berkeley

X. Dong

Uniqueness of Heavy Quarks in QCD

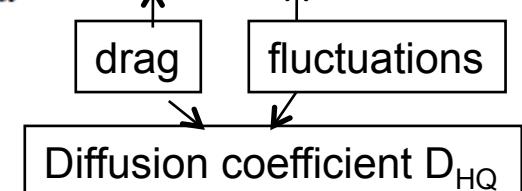


Zhu et al., PLB 647(2007)366

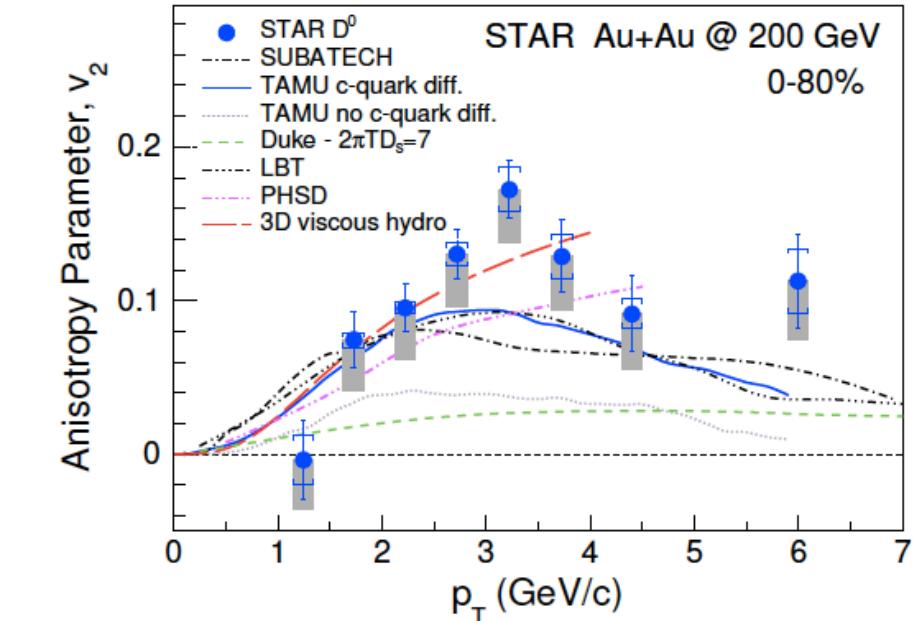
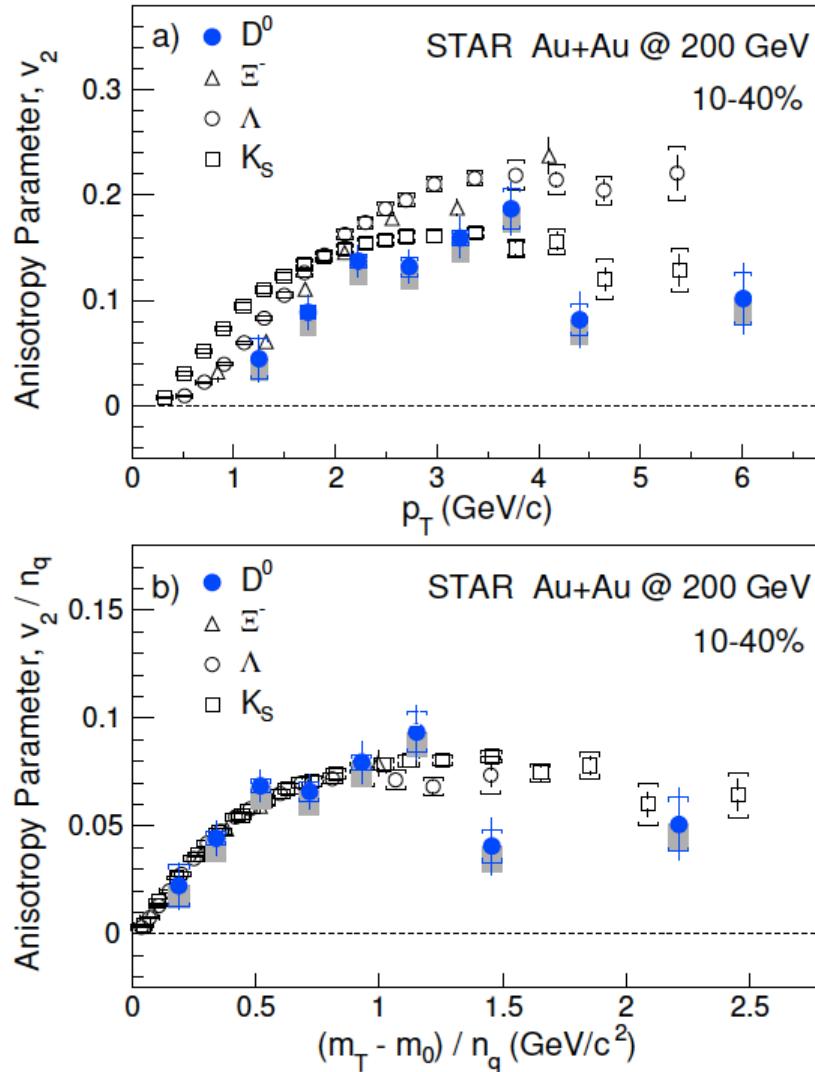


When $M_{HQ} \gg T$, $M_{HQ} \gg gT$

“Brownian” motion $\frac{dp^i}{dt} = -\eta_D p^i + \xi^i(t)$
 → Langevin simu.



D⁰ v₂ from STAR HFT



- v_2/n_q vs. $(m_T - m_0)/n_q$:
- D^0 mesons flow the same as light hadrons
- $D^0 v_2$ can be described by a 3D viscous hydro

Charm quark thermalized in the medium !

arXiv: 1701.06060

Open Bottom Production

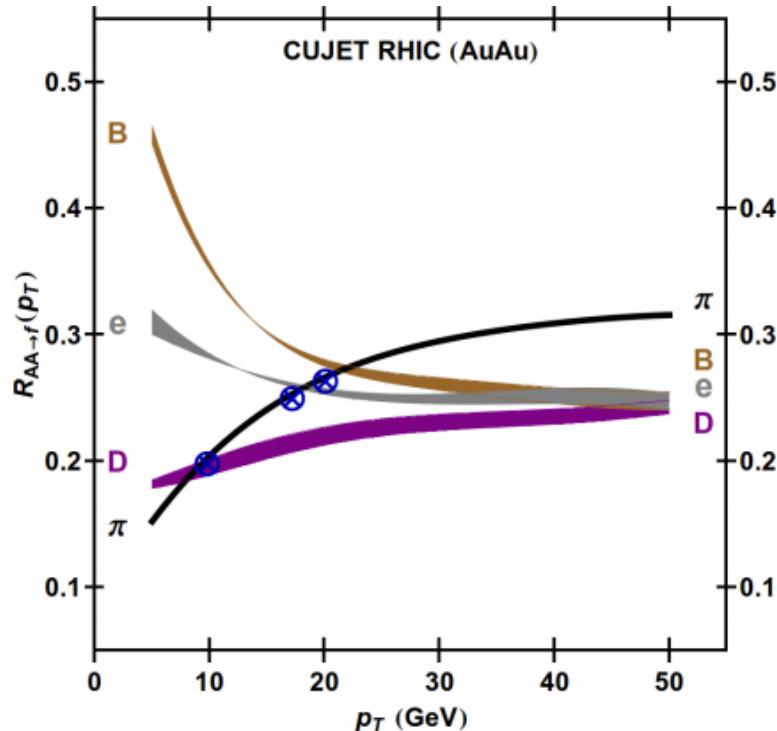
Open bottom production over a wide range of momentum

Flavor dependence of parton energy loss

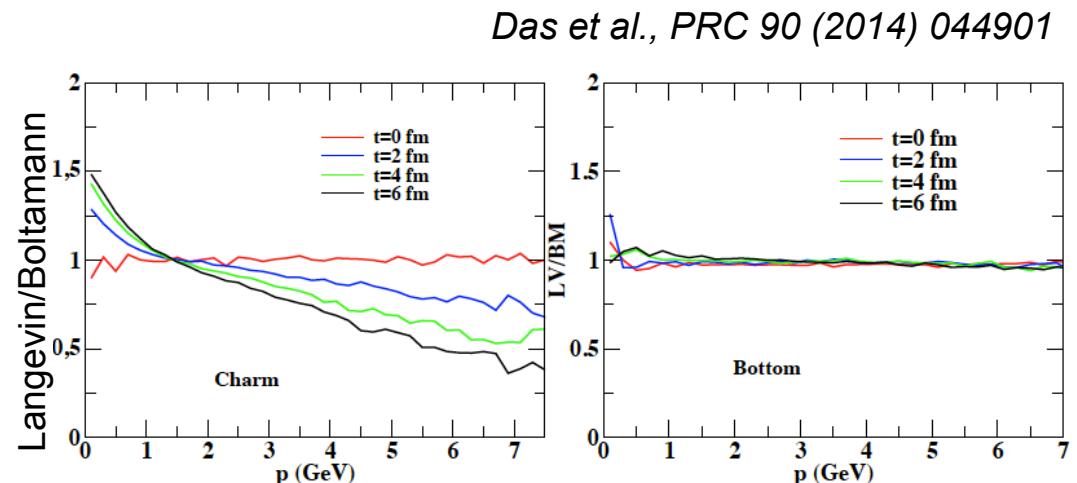
Cleanest probe to quantify medium transport properties – e.g. D_{HQ}

Total bottom yield for precision interpretation of Upsilon suppression

- **low p_T coverage is critical**



Buzzatti et al., PRL 108 (2012) 022301



Is charm heavy enough?

Sizable correction to the Langevin approach for charm
- may limit the precision in determining D_{HQ}

Physics Goal Section

2.1 B-meson physics at low p_T ($< 15 \text{ GeV}/c$)

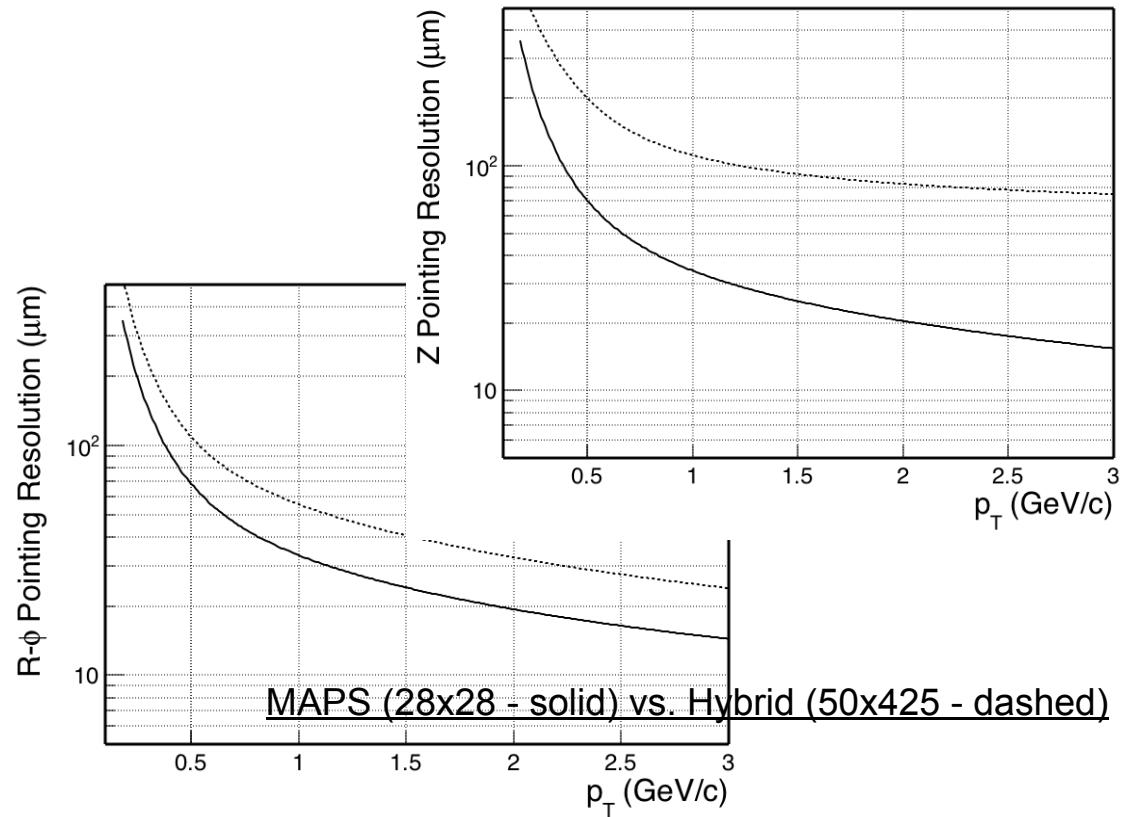
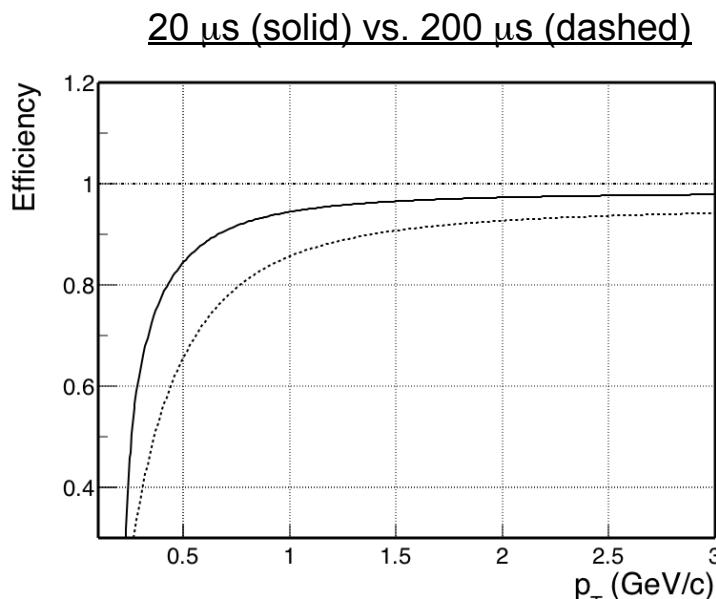
Revealed by the single electron R_{AA} data at RHIC, heavy quarks lose their energy when traversing the QGP medium through both radiative mechanism as well as elastic collisional mechanism. Recent charmed hadron data from RHIC and LHC show their R_{AA} are quite similar as that of light flavor hadrons. Theoretical calculations predict that bottom hadrons would be much less suppressed compared to charm and light flavor hadrons due to the much larger bottom quark mass in the p_T region of 5-20 GeV/c at RHIC[xx]. To systematically understand the flavor/mass dependence of parton energy loss mechanism, the next physics goal would be to measure and understand the bottom hadron production in heavy ion collisions.

Another unique feature that heavy quarks bring is that their motion inside the QGP medium can be treated in analogy to the Brownian motion when their masses are much larger than every momentum kick they suffer in the QGP. Therefore, one can simplify their dynamics through the QGP with a Langevin simulation and then access the heavy quark spatial diffusion coefficient ($2\pi TD_s$), the QGP medium transport parameter by comparing data and model calculations. Recent STAR HFT measurements reveal that the charmed hadron v_2 follows the same empirical ($m_T - m_0$) scaling as light hadrons at $p_T < 4 \text{ GeV}/c$ [xx]. This suggests charm quarks may have reached the thermal equilibrium. On the other hand, theoretical calculation also shows the Langevin simulation for charm quarks may have sizable corrections compared to the full Boltzmann transport. Both data and model calculations indicate that comparing charm hadron observables to Langevin simulation calculations may limit the precision of the extracted diffusion coefficient[xx]. To precisely determine the intrinsic QGP transport parameter, $2\pi TD_s$, measurements of bottom hadron production, particularly at low p_T region, will be critical.

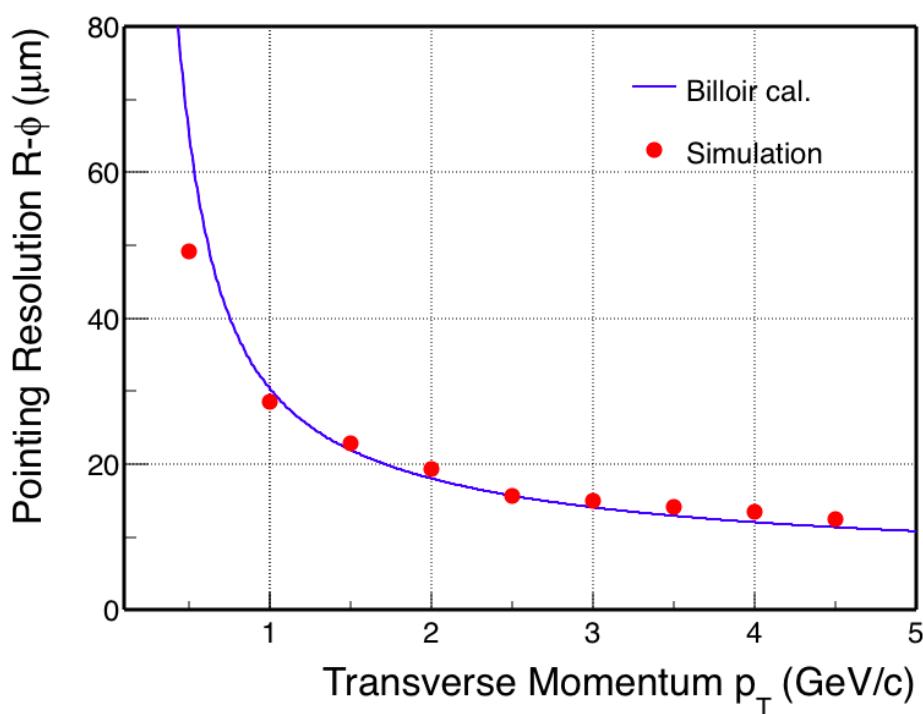
Furthermore, measuring the total bottom cross section in heavy ion collisions will be also crucial for the interpretation of the suppression in the bottomonia production, one of the highlighted sPHENIX measurements been proposed.

Requirements for Precision Open Bottom Production at RHIC

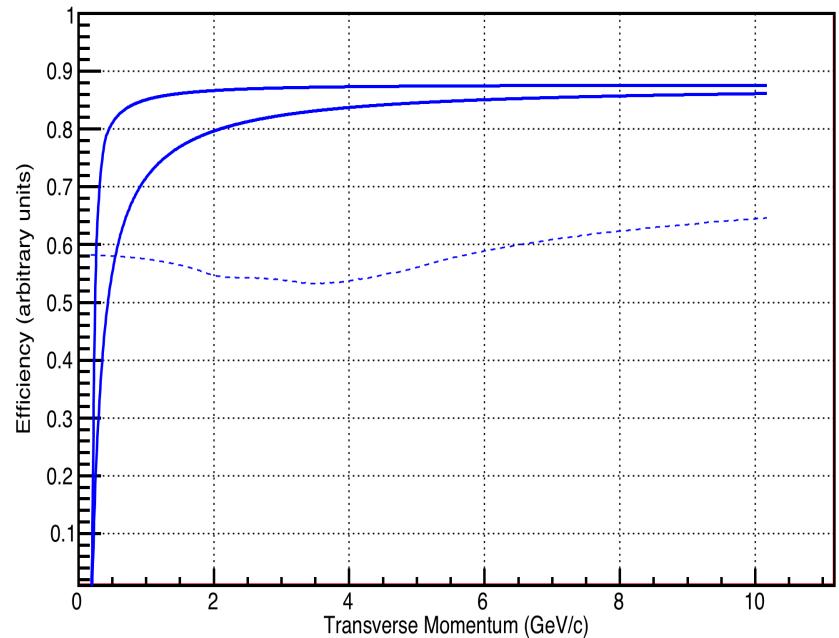
- High luminosity runs and large datasets (triggered and untriggered)
 $B \rightarrow J/\psi$, $B \rightarrow D$, $B \rightarrow e$, $B \rightarrow D\pi$ and b -jet etc.
- Fast silicon detector with ultimate pointing resolution
Next generation MAPS sensors with much shorter integration time $< 20 \mu\text{s}$ (vs. $186 \mu\text{s}$)
 - high efficiency at high RHIC luminosity, particularly at low p_T



Pointing Resolution and Efficiency



Single Track Efficiency for the HFT (D0 Efficiency dashed) .vs. Pt



80×10^{26} RHIC luminosity, central Au+Au 200 GeV collisions

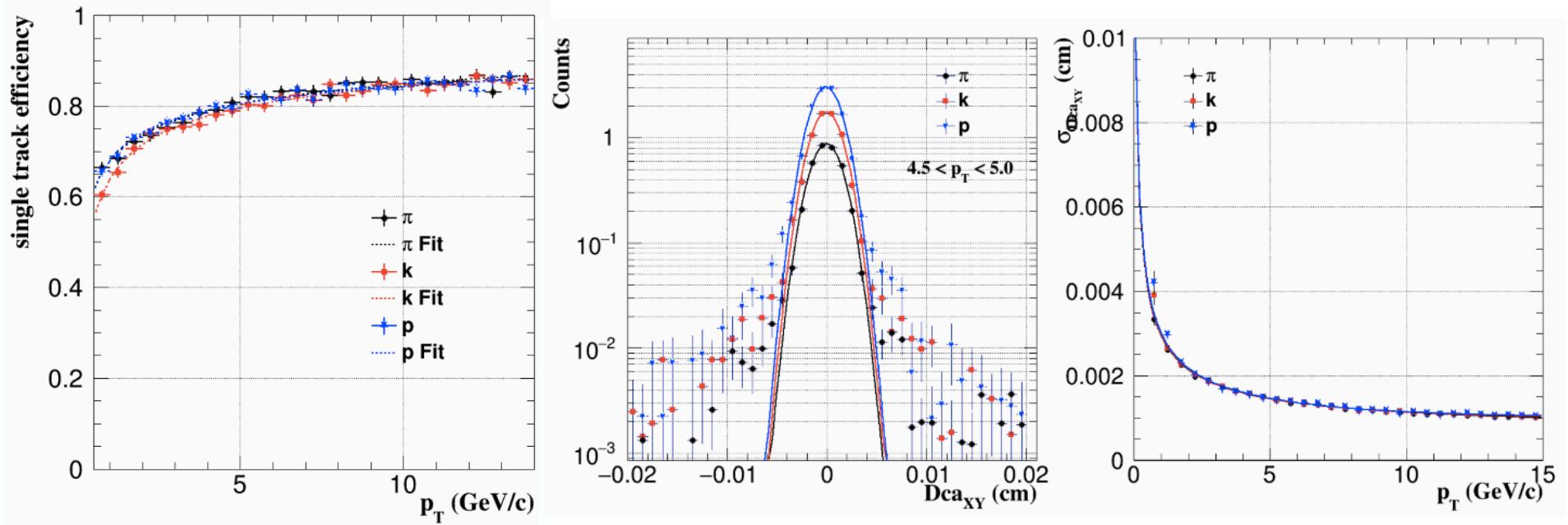
MAPS: 20 us integration time

MB pileup events and UPC hits included (small contribution)

Efficiency or good hit probability: inefficiency due to mis-association

$$\text{Efficiency/Good Hit Probability} = \frac{1}{1 + 2\pi R_{r\phi} R_z \rho} \quad R = \sqrt{R_{proj}^2 + R_{det}^2}$$

Full Hijing/GEANT Simulation + Fast MC for Performance Estimate



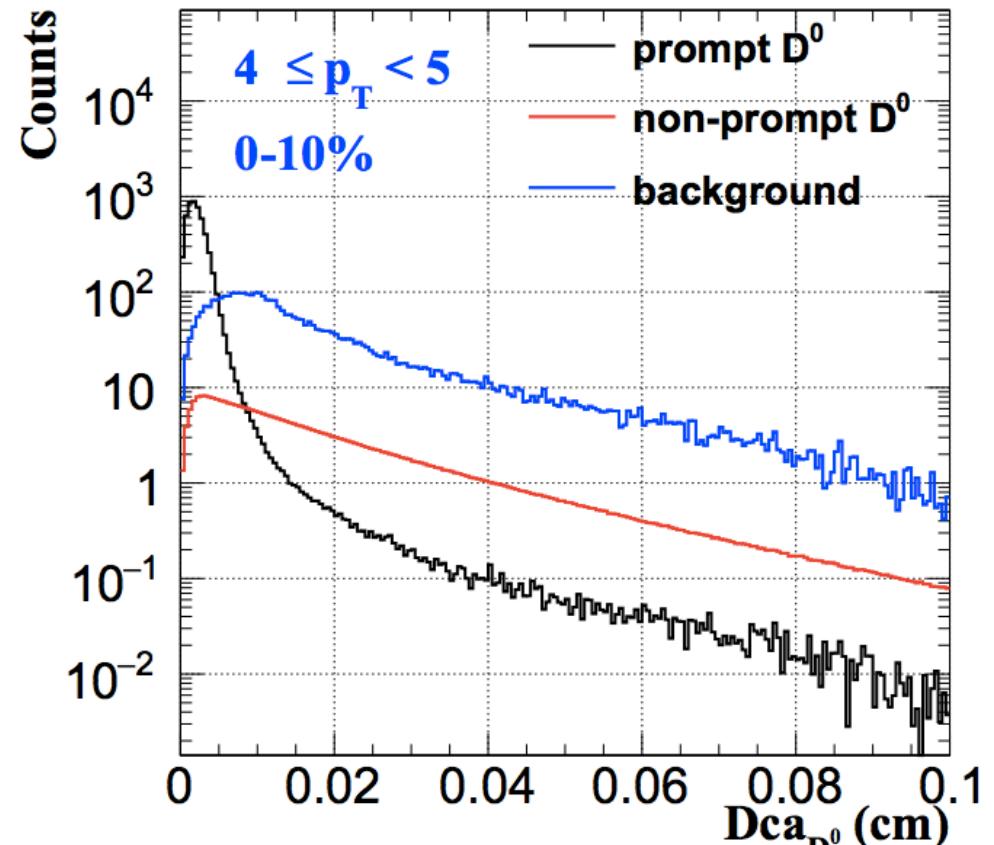
- Tracking efficiency and DCA distributions obtained from sPHENIX full GEANT simulation performance for single track with TPC+INTT+MAPS
- These distributions fed into a fast MC simulation (package used for STAR-HFT)
 - validated with MC for both signal efficiency and background rate

Goal: to capture full distributions for both signals and combinatorial backgrounds
- correlated background estimated based on corr./comb. ratios from STAR HFT

Physics Channels

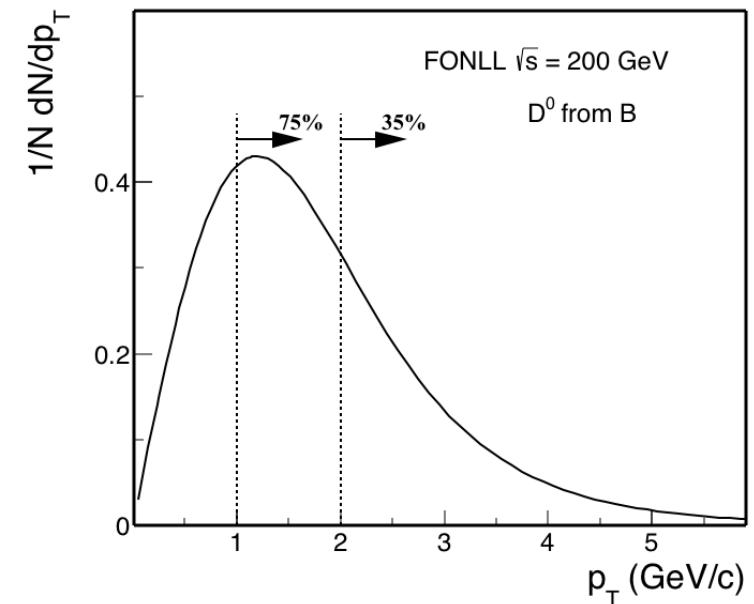
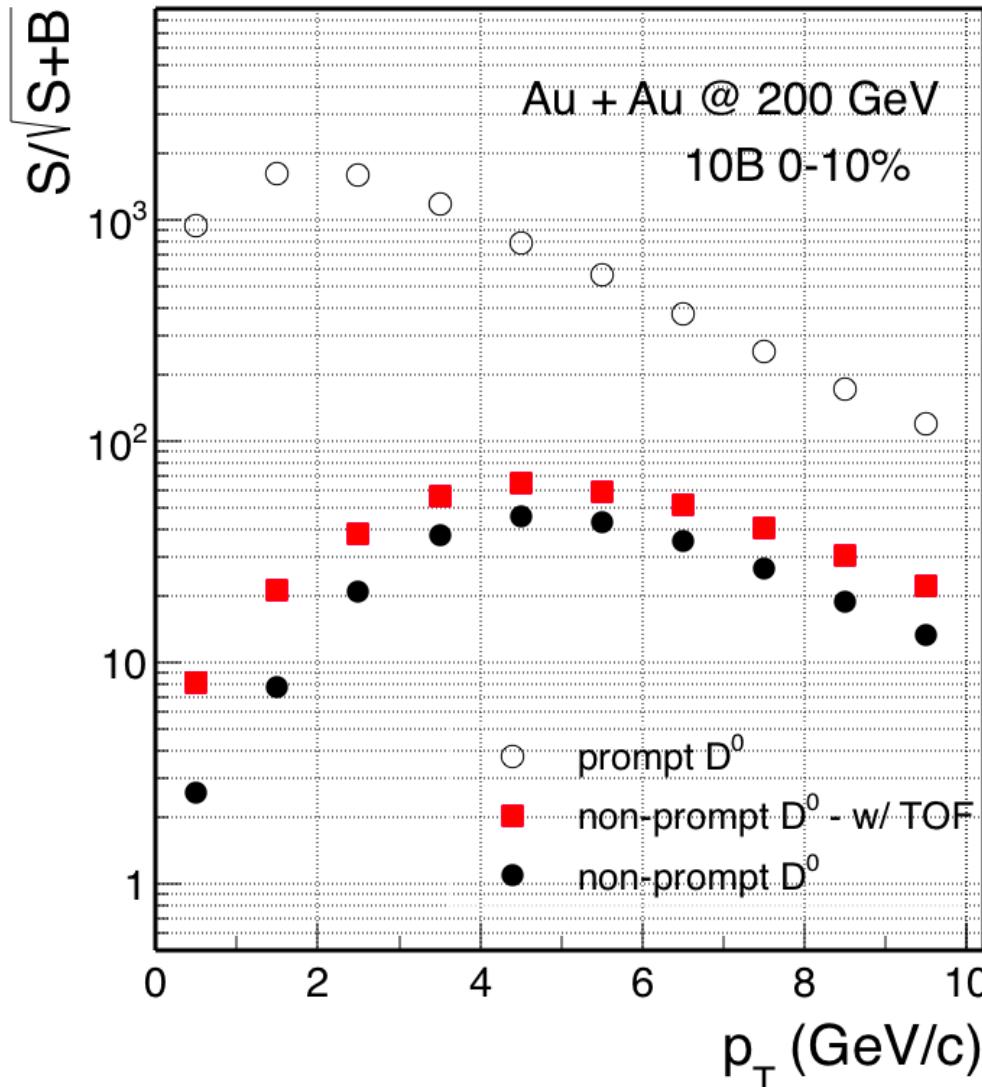
Hadron	Abundance	$c\tau (\mu\text{m})$
D^0	56%	123
D^+	24%	312
D_s	10%	150
Λ_c	10%	60
B^+	40%	491
B^0	40%	455
B_s	10%	453
Λ_b	10%	435

$B \rightarrow J/\psi + X$ 1.2%
 $B \rightarrow \bar{D}^0 + X$ 60%
 $B \rightarrow e + X$ 11%
 $B^+ \rightarrow \bar{D}^0 \pi^+$ 0.5% } Needed for $p_T < 10 \text{ GeV}$
 b-tagged jet - see Jin's talk



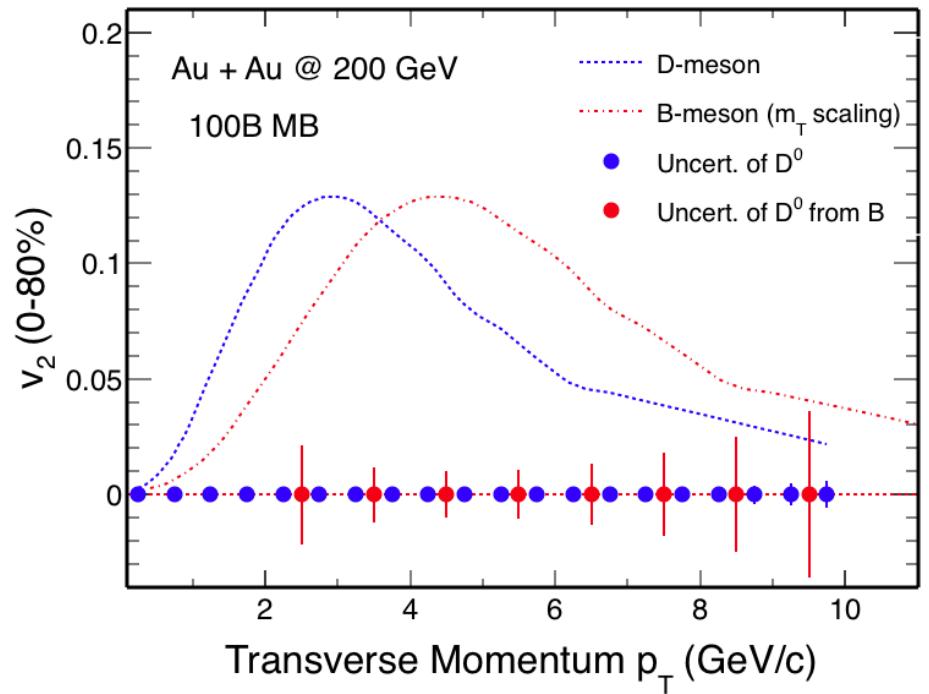
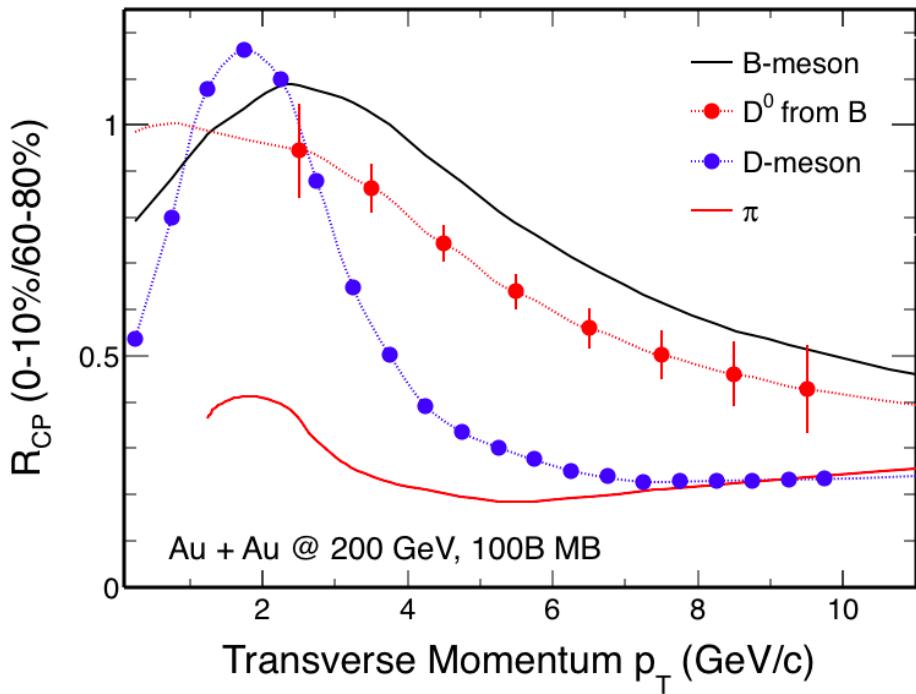
Topological cuts: default from STAR D^0 analysis

Estimation on Non-prompt D⁰ Significance



Good performance for measuring non-prompt D⁰ at low p_T with sPHENIX
PID detector (TOF) can help further improve particularly the low p_T precision
- constrain the total bbbar X-sec

R_{CP} and v_2 Projections for Non-Prompt D^0

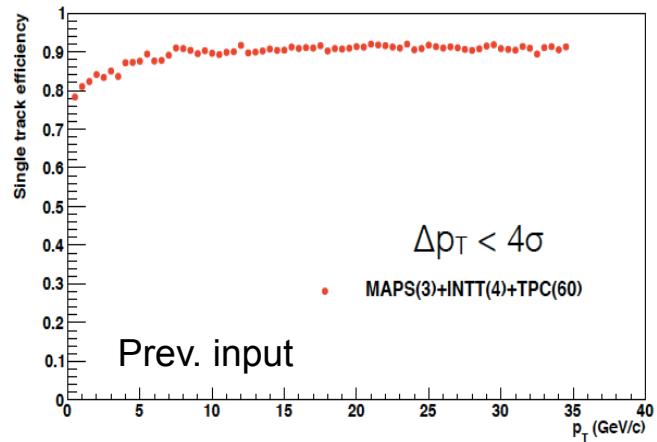
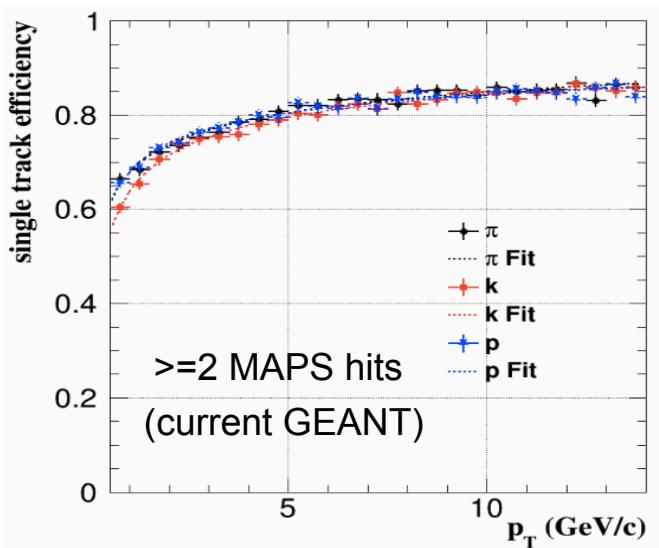
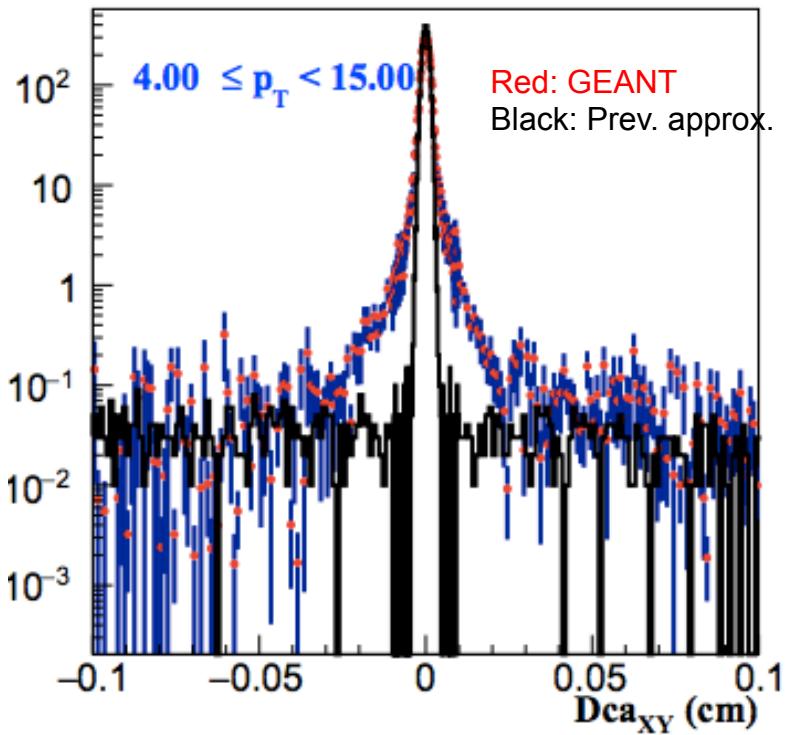


R_{CP} theory curves: average R_{AA} of calculations from Duke, TAMU and CUJET
 v_2 of D-meson: fit to STAR HFT D^0 data points

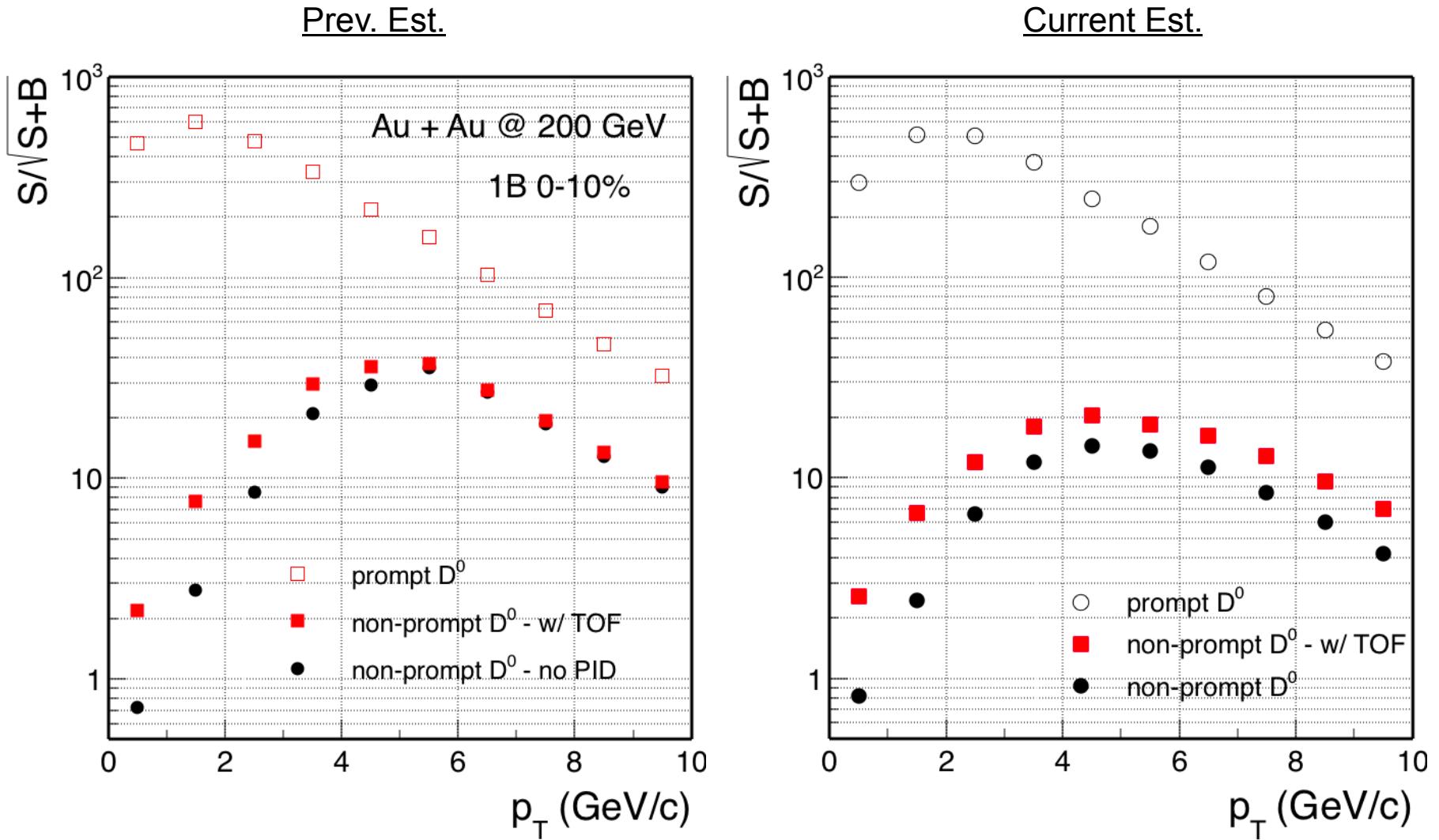
Assuming: Signal scales with N_{bin} , background scales with N_{part}^2

Backups

Input Comparison: GEANT vs. Prev. Approximation



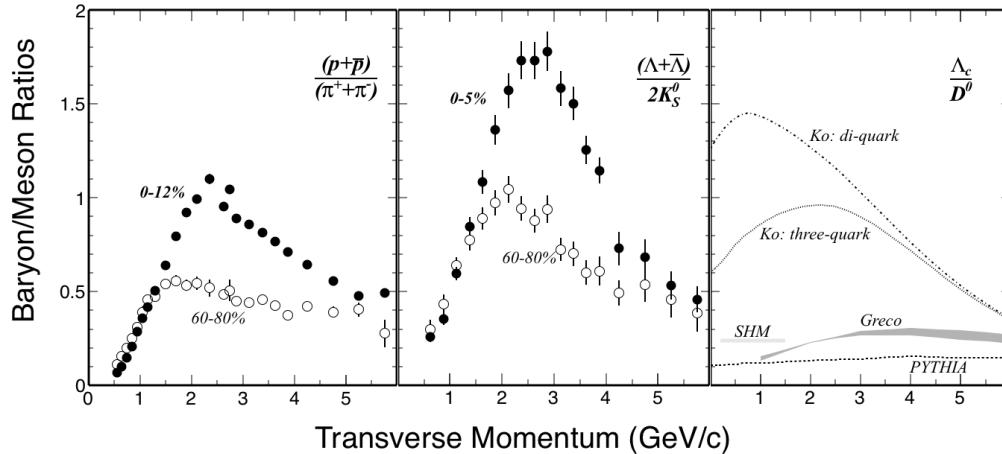
Performance Comparison



Λ_c and HQ Correlations

High statistics Λ_c measurements

Λ_c/D^0 enhancement sensitive to
 - charm quark hadronization,
 thermalization, domains in sQGP etc.

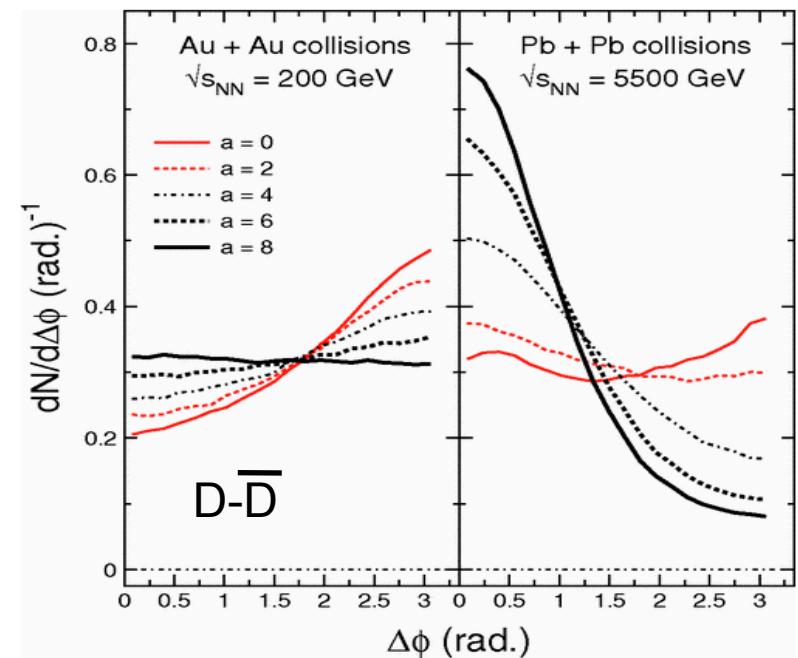


Lee et al, PRL 100 (2008) 222301

Ghosh et al, PRD 90 (2014) 054018

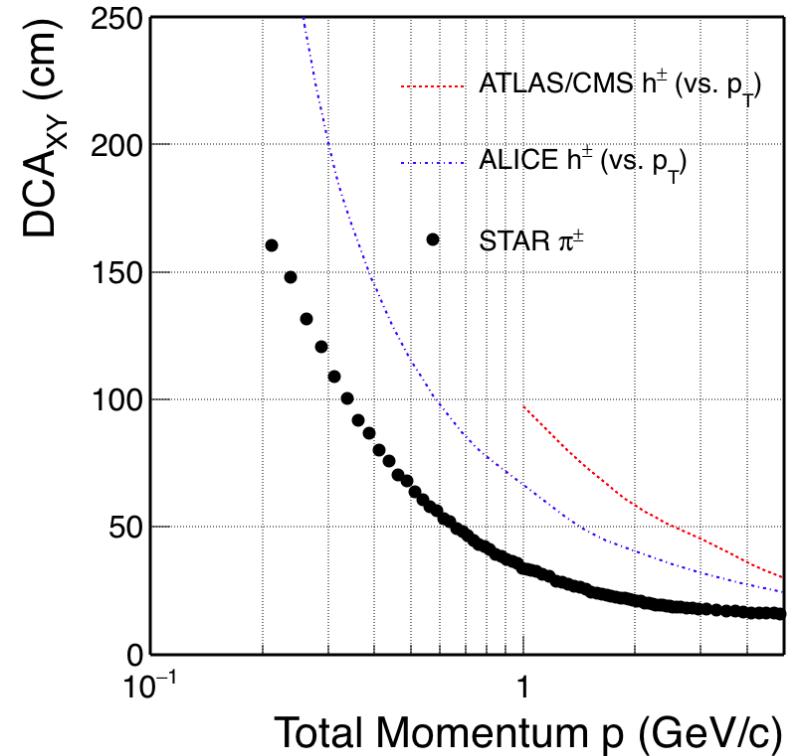
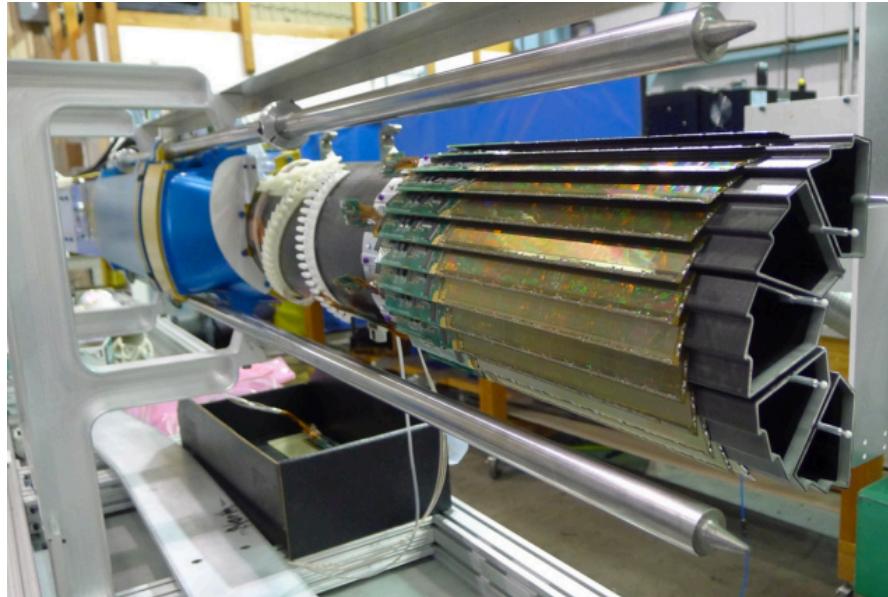
Heavy quark correlations

- More sensitivity to HQ-medium interaction, thus better determination of ΔE mechanisms and D_{HQ}
- LHC vs. RHIC – different initial pair correlation/medium dynamics



Zhu et al, PRL 100 (2008) 152301

STAR Heavy Flavor Tracker



STAR HFT/PXL – first application of MAPS pixel detector at a collider

- Aim for precision measurements of charmed hadron production in HIC
- PXL detector designed, developed and constructed (including mechanics) at LBNL
- First layer thickness: $0.4\%X_0$
- Pitch size $20.7 \times 20.7 \mu\text{m}$
- Integration time: 186 μs (see next page)

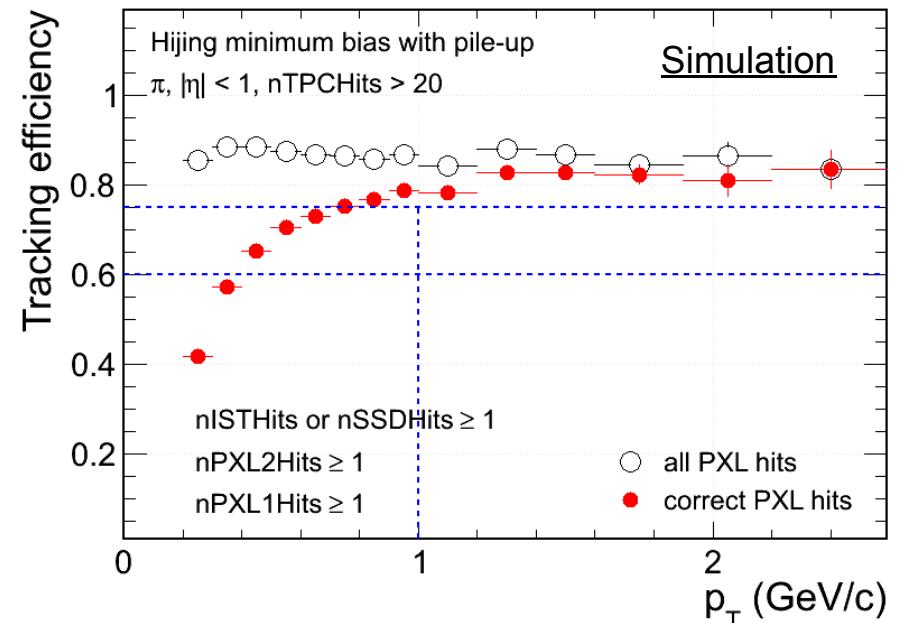
Hit Density on STAR PXL at RHIC Environment

Simulation@50kHz	PXL inner	PXL outer
Radius (cm)	2.8	8
MB pileup hits (cm^{-2})	13	~ 3
UPC electrons (cm^{-2})	33	~ 3
Total bkgd hits (cm^{-2})	46	~ 6
MB signal Au+Au (cm^{-2})	~ 8	~ 1
Au+Au MB real data (cm^{-2})	~ 50	~ 5

Signal hits fraction in MB (Central) events:
 ~15% (~30%) at PXL inner

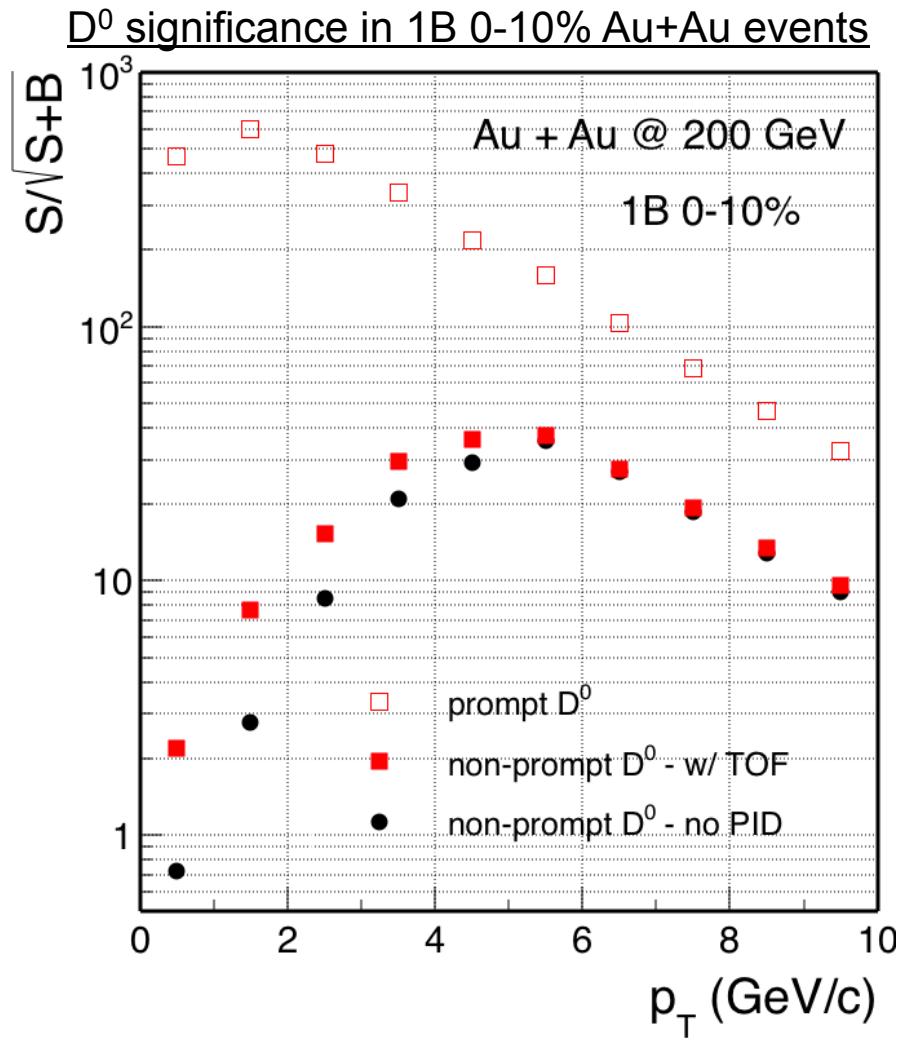
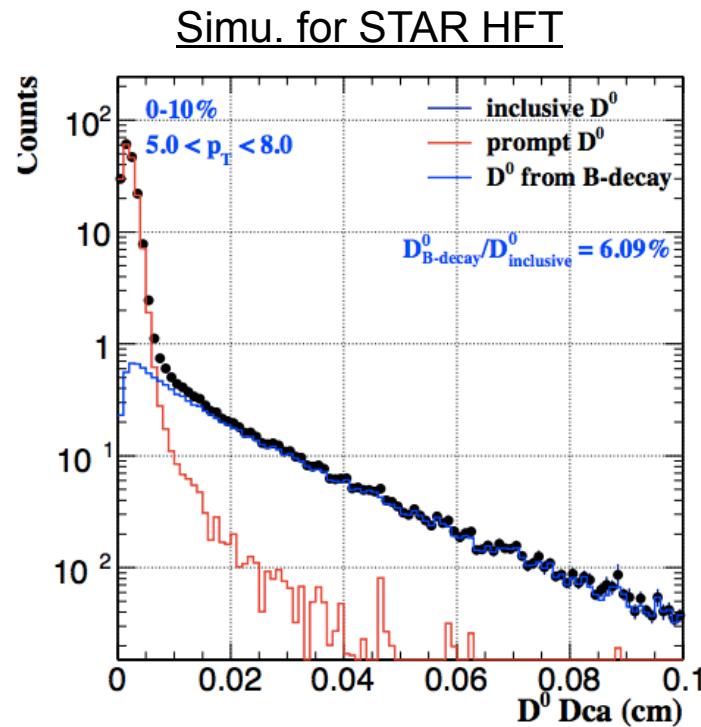
Increasing fake matches in low p_T

Technology chosen considering both
 physics and technology readiness



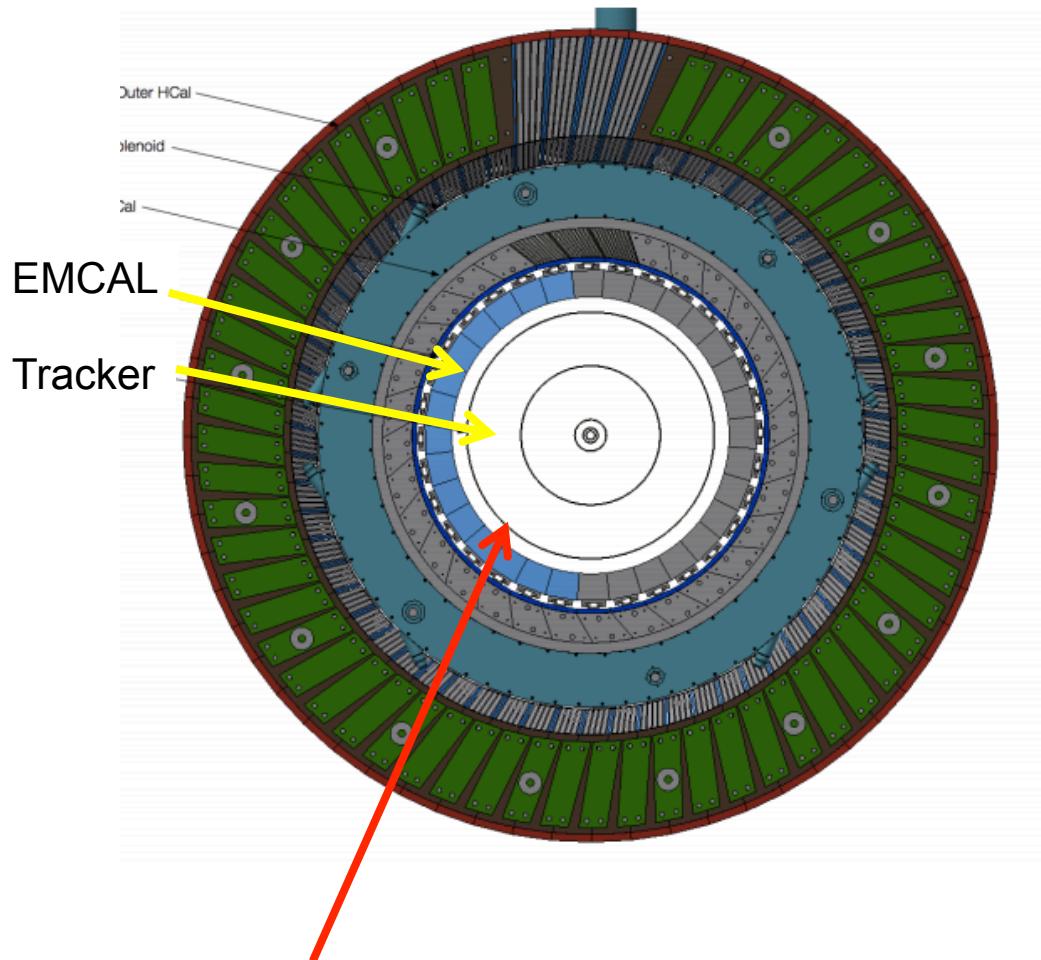
Estimation for Non-prompt D⁰ Measurements

Full signal and background simulation based on data-driven simulation package
 - validated with full GEANT simulation for the TPC+HFT tracking at STAR



D^0 cross section - STAR measurement
 Bottom cross section – FONLL* N_{bin}

Particle Identification with TOF



TOF PID requirement:

$$M = p \sqrt{\left(\frac{ct}{L}\right)^2 - 1}$$

$$\frac{\Delta M}{M} = \frac{\Delta p}{p} \oplus \gamma^2 \left[\frac{\Delta L}{L} \oplus \frac{\Delta t}{t} \right] \sim \gamma^2 \frac{\Delta t}{t}$$

STAR TOF:

Radius ~ 2.15 m, $\sigma_t \sim 65$ ps

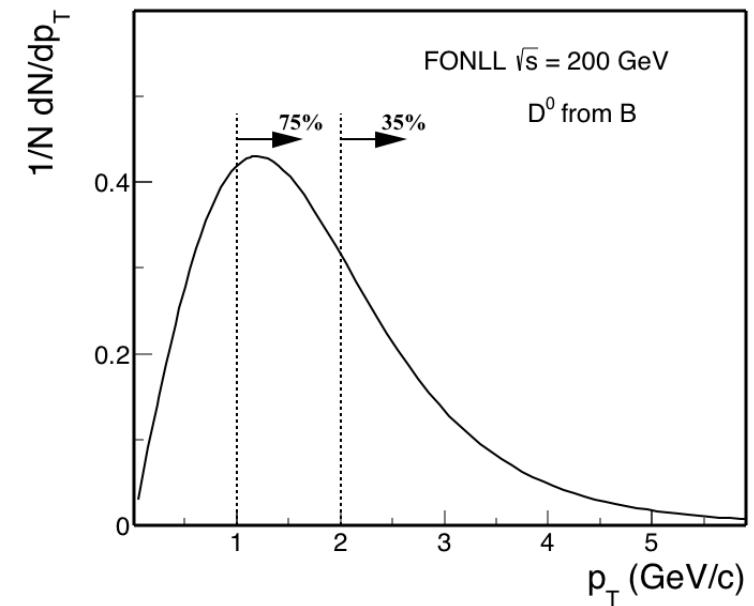
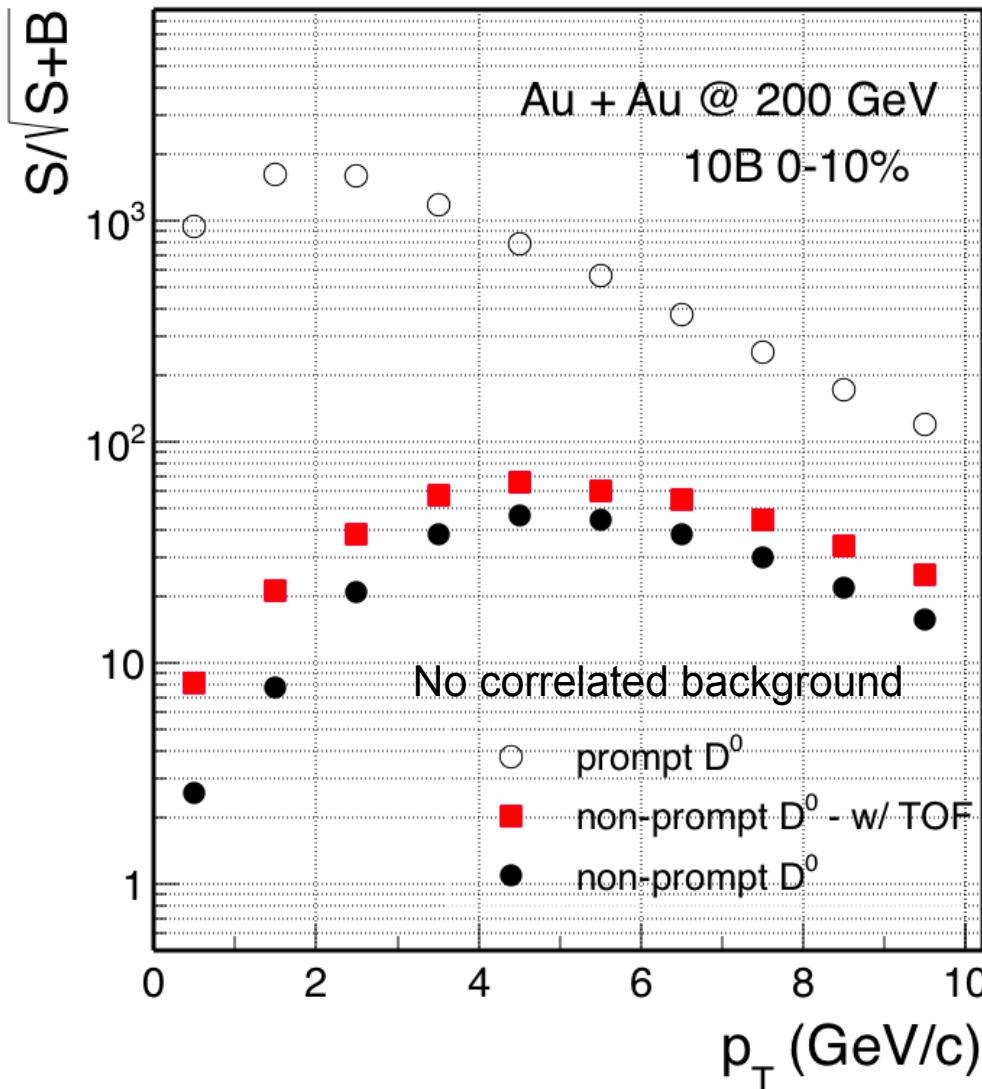
sPHENIX TOF

(to have the same PID capability)

Radius ~ 0.85 m, $\sigma_t \sim 25$ ps

Candidate: Many-gap MRPC

Estimation on Non-prompt D⁰ Significance



Good performance for measuring non-prompt D⁰ at low p_T with sPHENIX

PID detector (TOF) can help further improve particularly the low p_T precision
- constrain the total bbbar X-sec